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THE EFFECT OF COOLING MILK OVER A SURFACE COOLER ON FLAVOR, CREAM LINE AND EVAPORATION LOSS

by

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INTRODUCTION

One of the most important steps in milk plant operation is the cooling of the milk after pasteurization. It is essential that the milk be cooled quickly in order to maintain the low bacterial count and in such a way that there is the least possible injury to the creaming ability and flavor.

Cooling is usually accomplished by allowing the hot milk to flow over a surface cooler with cold water running through the top tubes and brine through the bottom tubes.

During the cooling process milk often freezes on the tubes of the cooler which may reduce the volume of cream rising on the milk and the flavor may also be affected. Some shrinkage due to evaporation of water from the cooler may also result.

The purpose of this work is to study some of the problems involved in cooling milk.

REVIEW OF LITERATURE

Various factors connected with this problem have received the attention of several investigators.

It is a well known fact that consumers judge the quality of milk by the depth of cream layer in the bottle. It is, therefore, necessary for the dealer to get as deep a cream layer as possible.

The most satisfactory method of measuring the cream volume is by use of graduated cylinders, according to Hammer (8).

Work by Trout (16), Hammer (8) and Whittiker et al (17), showed that low storage temperatures gave deep cream layers. At 32° F. a deep layer is formed which shrinks on standing. At higher temperatures 50 - 60° F. the layer grows deeper on standing.

Several investigators - Clement (2), Dahlberg and Marquardt (3), Hunziker (9) and Martin and Combs (11), have found that quick cooling without agitation gave the maximum cream layers. It is especially important to secure rapid cooling between 100° and 40° F.

Freezing at temperatures around 0° F. reduces the cream layer. Reid (14) (15) found that freezing at 0° F. for three hours and thawing for one hour at 60° F. reduced the cream layer 39 per cent. At the end of 24 hours, this reduction had increased to 46 per cent. Freezing for five hours at the same temperature gave the same reduction at the end of 24 hours but the reduction was somewhat larger for the first few hours of storage. Freezing at 30° F. gave a reduction of only one per cent.

Market milk investigations in New York (12) showed that the cream on Holstein and mixed milk was reduced by freezing but Jersey milk was not affected. The creaming ability of the former was restored by pasteurization.

Metallic flavors are sometimes caused by the cooler or other equipment with which the milk comes in contact. It is an accepted fact that copper causes off flavors in milk. Dissolved copper is blamed for a cardboard or cappy flavor by Gefhardt and Sommer (5). A tallowy or fishy flavor sometimes develops in milk from a plant that has a great deal of exposed copper in equipment. Some copper equipment seems to be satisfactory, however.

The flavor has been traced to coolers having spots of exposed copper. In one case Golding and Feilman (6) found the milk to contain from one to one hundred parts per million of dissolved copper, the larger amount being dissolved when air had access to the copper spots.

It is possible that different reactions cause different flavors, although the same metal is involved. Hunziker (10) is of this opinion and states that the flavor may be immediately metallic at times and at other times some other flavor.

Milk often has a cappy flavor. It is usually so slight, however, that the average consumer does not notice it.

Okuyama (13) states that the flavor does not develop for from 24 to 72 hours after the milk is processed. The flavor was found in the product of one plant and samples were taken at various points in the plant and examined for flavor. The flavor appeared from the cooler onward. The cooler was retinned and the flavor disappeared.

Davies (4) states that fats may volatilize to give the same volatile products that give cardboard its characteristic flavor.

A metallic flavor may develop in milk and not be caused by metals. Guthrie (7) found the flavor developed in buttermilk in sterile glass bottles. When other milk was inoculated with the buttermilk, it developed the flavor.

EXPERIMENTAL PROCEDURE

Market milk from the college dairy was cooled in various wyys. Three coolers were used, cooler "A" was a Cherry tinned copper cooler with a water section consisting of six, two inch tubes and a brine section of four, two inch tubes and had a capacity of 2,000 pounds per hour. Cooler "B" was a Farrington Junior milk cooler made by the Creamery Package Manufacturing Company. There were seven, one and one-fourth inch tubes in both the water and brine sections, capable of cooling approximately 1,000 pounds per hour. Cooler "C" was a "D. K." dairy cooler purchased from Meyer-Blanke Company and consisted of brine and water sections of eight, three-fourth inch tubes each and had a rated capacity of 900 pounds per hour. This rating calculated cooling the milk from 90°F.

The creaming ability of the various samples of milk was measured by placing samples of the milk in cream line cylinders graduated to read direct the per cent of cream by volume rising to the surface.

The Babcock test was used in making butter fat determinations, and the lactometer was used to determine the total solid content of the milk. In part III dealing with evaporation losses during cooling the Mojonnier method was used in making fat and total solids determinations.

The refractive index was determined on an interference refractometer by the method suggested by Adams (1).

The flavor of the milk was determined by submitting samples to several judges who were familiar with the judging of milk.

A standard potentiometer and a saturated KCl calomel half cell made by Leeds and Northrup Company, was used in making pH determinations. The electrode used was of gold wire. The same equipment was used in determining oxidation reduction potentials except that saturated KCl agar bridges and platinum wire electrodes were used.

The experiment was divided into three parts consisting of:-

I. The Effect of Cooling Processes on Cream Line
  a. The effect of freezing and alternate freezing and thawing.
  b. The effect of different brine temperatures.
  c. The effect of different rates of flow of milk over the cooler.
  d. The effect of the temperature to which the milk was cooled.
  e. The effect of freezing or partial freezing on the appearance of the cream layer.
II. The Effect of Cooling Processes on the Flavor of the milk.
  a. Effect of freezing on the cooler on the flavor of the milk.
  b. Effect of various methods of sterilizing the cooler on the flavor of the milk.
III. A Study of Evaporation Losses Resulting from Cooling.

The Effect of Cooling Processes on Cream Line

The Effect of Freezing and Alternate Freezing and Thawing. Three trials were made in which milk was heated to 142°

F. and pumped over cooler "A". The temperature and rate of flow of brine through the cooler was adjusted so that the milk froze on the brine section. Samples of the milk were taken before any freezing took place, near the middle of the cooling process, and of the frozen portion. The milk was analyzed for fat and total solids and samples set for creaming. One trial was also run on cooler "B", and another trial was made in which the milk was permitted to freeze and thaw alternately during the cooling process. Samples were taken, while the milk was freezing on and thawing off the cooler, and set for creaming. All samples were also judged for flavor as will be discussed later. The results are shown in Tables I and II.

In Table II, sample 3 is taken between samples one and two but the grouping used in the table gives a better comparison.

The average of four trials shows that after 24 hours storage the first milk over the cooler and the middle portion were equal in volume of cream rising, the volume being 13.75 per cent of the milk.

TABLE I.

The Effect of Freezing on the Tubes of an External Tubular Cooler on the Cream Layer

	Per cent by volume of cream rising at the end of				Composition of milk	
	2 hrs.	4 hrs.	6 hrs.	24 hrs.	Fat Per cent	Total Solids Per cent
Trial 1 Cooler A						
First Over	15	14.5	14.5	12.0	4.10	
Middle of Run	15	14	14	11.5	4.20	
Frozen Portion	4	4	4	6	3.40	
Trial 2 Cooler A						
First Over	16	16	16	14.5	4.25	13.65
Middle of Run	16	16	16	14	4.20	13.50
Frozen Portion	8	8.5	8.5	9	3.60	12.05
Trial 3 Cooler A						
First Over	17	16.5	16	15	3.90	12.70
Middle of Run	17	16.5	16	15	4.20	12.89
Frozen Portion	8.5	8	9	9	3.80	11.25
Trial 4 Cooler B						
First Over	15	14	14	13.5	4.10	13.45
Middle of Run	17.5	17	15	14.5	4.20	13.40
Frozen Portion	10	10	10	9.5	3.80	12.63
Average of 4 trials						
First Over	15.75	15.25	15.13	13.75	4.09	13.27
Middle of Run	16.38	15.88	15.25	13.75	4.20	13.26
Frozen Portion	7.63	7.63	7.88	8.38	3.53	11.99

TABLE II

The Effect of Alternate Freezing and Thawing of Milk on the Tubes of the Cooler on Cream Layer

Series I Cooler B						
	Per cent by volume of cream rising at the end of				Composition of milk	
					Fat	Total Solids
	2 hrs.	4 hrs.	6 hrs.	24 hrs.	per cent	per cent
Sample during freezing	20.0	18.5	18.25	16	4.50	14.15
Sample during freezing	20.0	19.0	18.5	16	4.50	13.88
Sample during thawing	20.0	19.0	18.5	17	4.40	13.98
Sample during thawing	19.5	18.5	18.25	16	4.40	14.13

The cream layer on the frozen milk, however, was reduced to 8.25 per cent. This is a reduction of 50 per cent in volume of cream layer. The difference was even greater when the cream line formed but the cream layer on the frozen milk deepened while on the unfrozen milk, it shrank.

An analysis of the frozen portion showed that the fat content was reduced from 4.20 to 3.55 per cent and the solids from 12.27 to 11.29 per cent, which no doubt is one cause of the reduction in cream volume.

It may be concluded from the results shown in Table II that the effect of freezing on creaming ability of milk is so slight in ordinary plant practices, that it passes unnoticed. It is possible that the milk which actually freezes does not cream normally but this is an insignificant amount.

The Effect of Different Brine Temperatures. Four trials were made in which brines at 0, 1, 10 and 12° F. were compared with brines at 18, 20, 30 and 22° F. and the effect of the various temperatures on creaming ability studied. The results are shown in Table III.

It may be concluded from these data that brine temperature has no effect on the creaming ability of milk. There is a slight tendency towards increased cream layer with the higher brine temperature but this is too small and irregular to be conclusive.

TABLE III.

The Effect of Various Brine Temperatures on the Creaming Ability of Milk

Series 4 Cooler B						
	Brine Temperature °F	Per cent of cream by volume rising at the end of				Temperature to which milk was cooled °F
		2 hrs.	4 hrs.	6 hrs.	24 hrs	
Trial 1	0	16	16	15.5	14	
	18	15	14.5	14.5	15.5	
Trial 2	1	16.5	16	15.5	14	40
	20	17.5	17	16	15	40
Trial 3	12	14	13.5	13	12	38
	30	15	14	14	13	40
Trial 4	10	18	17.5	17	16	38
	22	18	17.5	17	16	46
Average of 4 trials	5.75	16.1	15.8	15.3	14	38.7
	22.50	16.4	15.8	15.4	14.6	42

The Effect of Different Rates of Flow of Milk Over the Cooler. Milk was cooled over the cooler "B" using one slow and one rapid rate of flow. Milk was also cooled over cooler "C" using four rates of flow. The results are shown in Table IV.

These data indicate that the only effect the rate of flow has on the cream layer is indirectly through the temperature to which the milk is cooled. It seems also that there is a temperature around 55° F. at which maximum creaming occurs. There is a tendency for smaller cream layers as the temperature increases. This tendency is not especially great, however, and has practically disappeared at the end of 24 hours.

It will be noticed that the differences in cream volume tend to disappear as the time of setting increases. The temperatures also tend to draw together as the milk is allowed to set. The tendency for cream layers and temperatures to draw together parallel each other but this may be only accidental.

TABLE IV

The Effect of the Rate of Flow of
Milk Over the Cooler on its Creaming Ability

	Per cent by volume of cream rising at the end of				Temperature °F. at the end of				
	3 hrs.	6 hrs.	10 hrs.	24 hrs.	0 hrs.	1 hrs.	3 hrs.	6 hrs.	24 hrs.
Series 5 Cooler D									
Fast 1*	20.3	19.5	18.5	14.0					
2	21.0	20.5	19.5	15.0		34	31.5	31.5	31.5
Slow 1	20.0	19	19 –	15.0					
2	19.5	19	19 –	15.0		32	32	31.5	31.5
Fast 1	20.0	22	21	18.0					
2	23.0	21.5	21	18.0	40	36	34	33	35
Slow 1	22.5	21	21 –	18.0					
2	21.0	20.5	21 –	19.0	40	36	34	33	36
Series 6 Cooler C									
Slow (Trial 1)	23.0	21	20	17.5	35	31	33	33	36
Increased Flow	23.0	21.5	21 –	16.0	38	35	30	34	36
Increased Flow	22.0	21	22	16.0	36	35	35	34	36
Rapid Flow	21	19	19	17	35	35	33	34	36
Slow (Trial 2)	25.5	22	21	15	37	32	32	31.5	32
Increased Flow	23	21.5	20	13	36	33	32	31.5	32
Increased Flow	23	22	20.5	16	41	33	32	31.0	32
Rapid Flow	21	20	19.5	16	40	34	32	31.5	32
Slow (Trial 3)	24.5	23	21.5	18.6	36	31.5	31.5	33	35
Increased Flow	24	22.5	21 –	18	38	31.5	31.0	33	35
Increased Flow	25	21.5	21 –	18	44	31.5	31.5	33	36
Rapid Flow	23.5	20	20	18	45	31.5	31.5	33	35

* 1 and 2 are from the same batch.

The Effect of Distance of Fall of Milk Over the Cooler on its Creaming Ability. Milk was cooled over cooler B, which had a total distance of fall of 32 inches and compared with milk cooled over cooler C which had a fall of 19 inches. In this trial ice water was used in the brine section of cooler C. The results are shown in Table V.

The data in Table V bear out the results of the previous section as to the importance of storage temperature. The same storage temperatures gave the maximum cream layer in both trials. It will be noticed that the nearer 35° F. the milk was cooled, the larger the cream layer, regardless of variations in the factor being studied.

TABLE V.

The Effect of Distance of Fall of Milk Over the Cooler on its Creaming Ability

	Per cent of cream by volume rising at the end of				Temperature °F. after				
	2 hrs.	4 hrs.	6 hrs.	24 hrs.	0 hrs.	2 hrs.	4 hrs.	6 hrs.	24 hrs.
Trial 1									
Cooler B,1	23	21.5	20	18	38	32	34	34	36
2	23	21.5	20	18	38	32	34	34	36
Cooler O,1	22	22	21	18.5	38	32	34	34	36
2	24	22	21	18	38	32	34	34	36
Trial 2									
Cooler B,1	22	20	20	17.5					
2	22	20.0	20	17.5	36	32	32	32	36
Cooler O,1	21	20 -	19	17					
2	21	20	19.5	17	41	33	33	33	36
Trial 3									
Cooler B,1	27	24	23	19					
2	26	23.5	22.0	18	34	32	32	32	34
Cooler O,1	26	22.5	22.5	18.5					
2	26.5	24	23	19	33	32	32	32	34

The Effect of the Temperature to Which Milk is Cooled and at which it is Stored on the Creaming Ability. A study was made of the effect of cooling milk to and storing it at various temperatures, on the depth of the cream layer.

Milk was cooled to 35, 40, 45 and 50° F. and triplicate samples were placed in cream line cylinders. One set of samples was stored at 35° F. in water, one set at 45° F. in water and one set at 45° F. in air. Check cylinders were set containing raw milk, taken from the vat. Readings were taken at the end of 1, 3, 6 and 18 hours. The results of the 18 hour readings are shown in Table VI.

The temperature at which the milk is stored affects the depth of the cream layer. The lower the temperature down to 35° F. at least, the deeper will be the cream layer.

The temperature to which the milk is cooled seems to have only a temporary effect on the cream layer. If it is cooled to a low temperature the cream layer will be deeper for the first few hours, but as it approaches the temperature of the surrounding media, the effect of the temperature when placed in storage disappears.

TABLE VI

Per cent of Cream Rising on Milk Cooled to Different Temperatures After Pasteurization and Stored Under Various Conditions

Treatment of Milk	Storage Temperature °F.	Per cent of Cream by Volume Rising at the end of 10 hrs. Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Average
Raw	35 in water		18	18	16	18.5	17	17.5
	45 in "		17.5	16	16	16	16	16.3
	45 in air		16	16	16.5	16	16	16.1
Pasteurized cooled to 35°F.	35 in water	18	18.0	18	17	19	18	18.3
	45 in "	15.5	15	16	15	16.5	15.5	16.1
	45 in air	15.5	18	17	16	16	16	16.4
Pasteurized cooled to 40°F.	35 in water	17	20	18	18	18	18	18.3
	45 in "	16	18	17.5	16	16.5	16	16.7
	45 in air	17.5	17.0	16.5	16	16.5	15.5	16.4
Pasteurized cooled to 45°F.	35 in water	17.5	15	16	18	16	16	16.5
	45 in "	16.5	18	15	17	17	16	16.6
	45 in air	17	16	16.5	17	17	16.5	16.8
Pasteurized cooled to 50°F.	35 in water	19	19.5		17.5	18	18	18.8
	45 in "	17	18		16	16.5	15.5	16.6
	45 in air	17	18		16	16	15.5	16.5

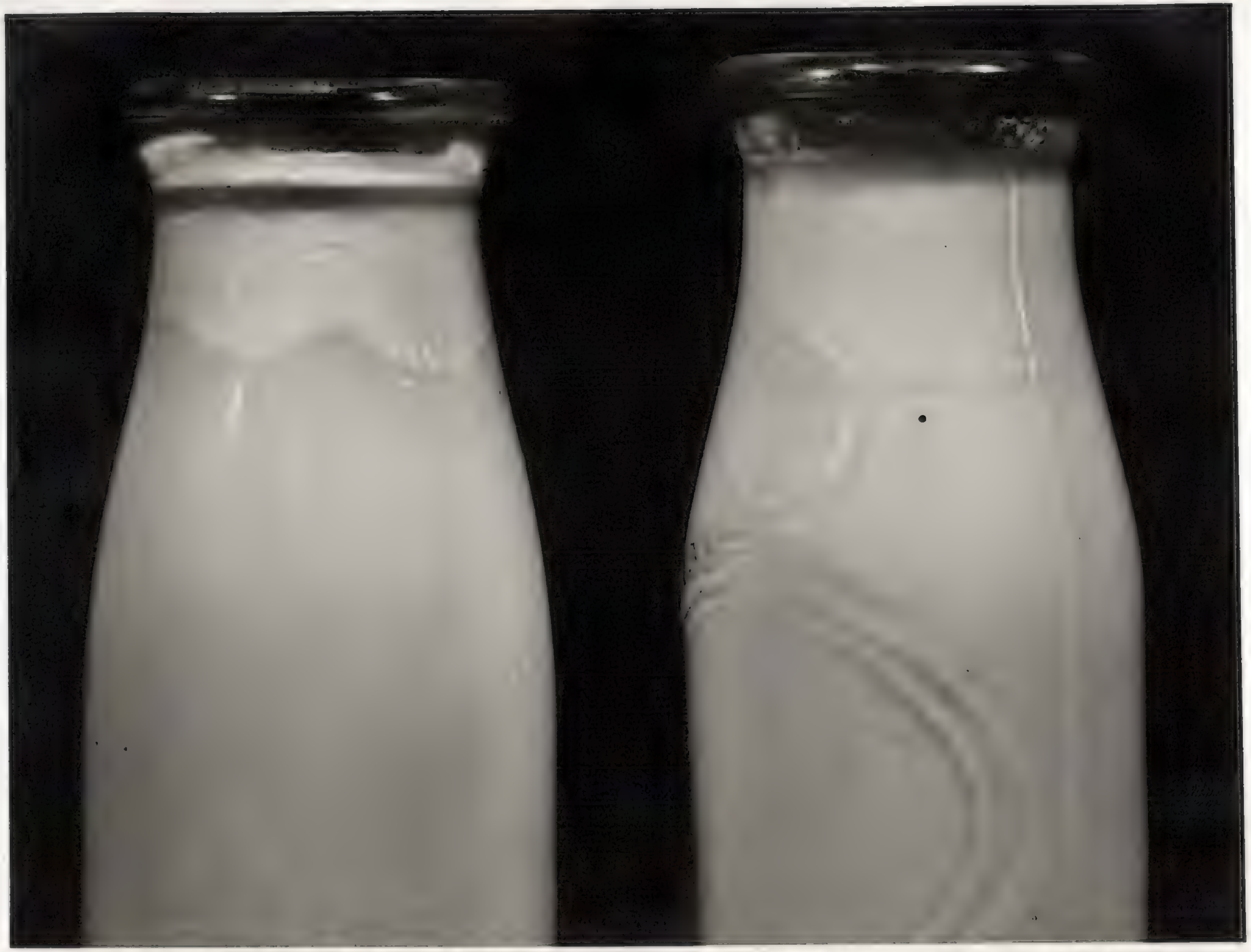
The Effect of Freezing or Partial Freezing on the Appearance of the Cream Layer. A study of frozen milk showed that the cream would not remix with the serum solids without vigorous shaking and even then it remained in small lumps. The cream line was very uneven and the cream layer had a curdled appearance.

Several samples of milk were frozen, some before and some after the cream line had formed. Milk was also allowed to freeze on the tubes of the cooler and bottles filled with the ice and the ice allowed to melt and the cream line form. All samples whether frozen before or after the cream line formed or on the cooler, showed the uneven cream line and the cream refused to remix readily. The harder the milk was frozen the greater was this effect.

Microscopical examination indicated a partial destabilization of the milk emulsion.

The clumps were found to be soluble in ether, disintegrate on heating, came to the top when centrifuged and had no crystaline shape. This would indicate that they were fat. Some of them were also disintegrated by a strong alkali solution indicating that they might be casein.

Figure I shows the effect of freezing on the appearance of the cream layer. Figures II and III show the appearance of the cream layer under the low power of the microscope.



Cream Line on Frozen Milk Cream Line on Normal Milk

Figure I.

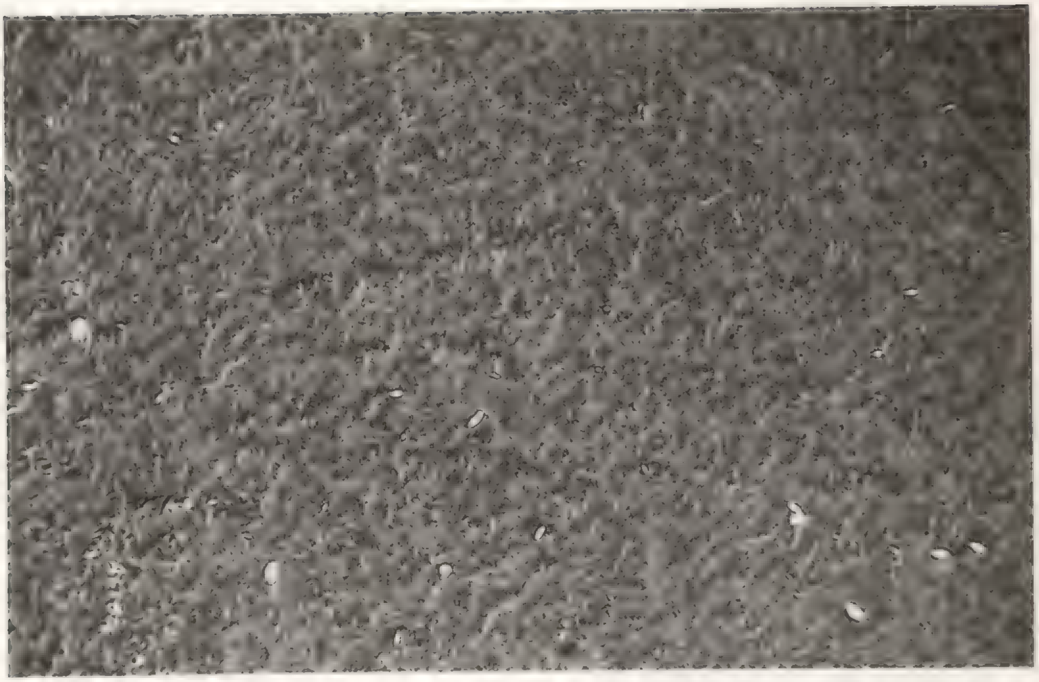


Figure II. Microscopic Appearance of Cream Taken from Normal Milk

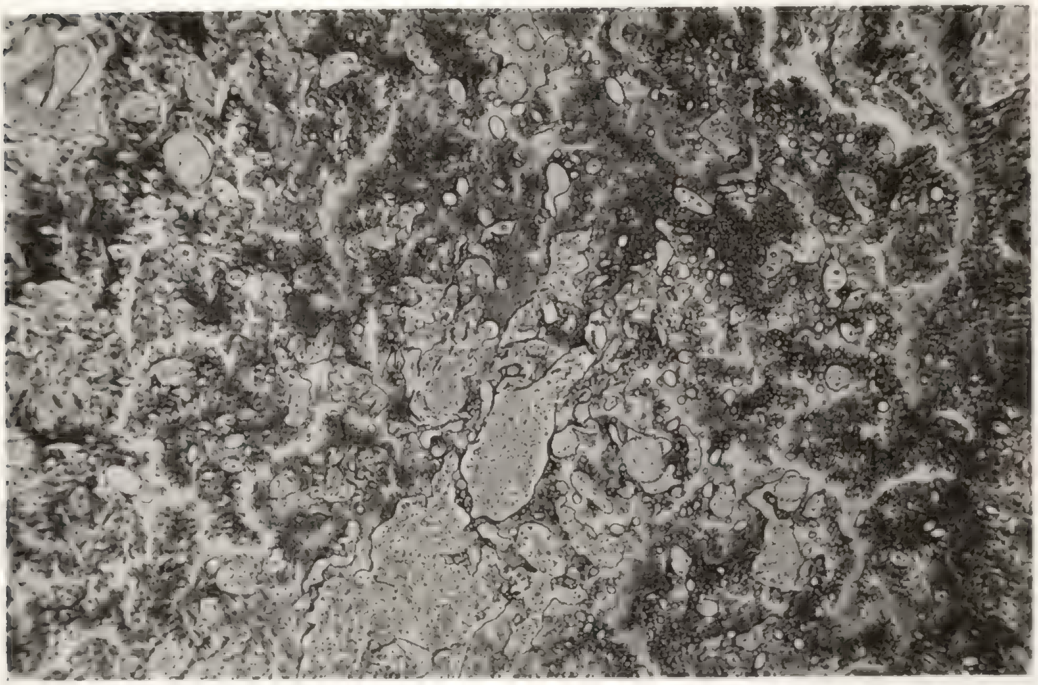


Figure III. Microscopic Appearance of Cream Taken From Frozen Milk

The Effect of Cooling Processes
on the Flavor of the Milk

The Effect of Freezing on the Cooler on the Flavor of the Milk. Samples of milk from part I of this experiment were taken for flavor tests. Giving the unfrozen milk a score of 22, the frozen portion was scored 18-19 and criticized as being watery, metallic and oxidized. The flavor seemed to be the same immediately and after 24 hours storage at about 50° F. In the trial where samples were taken while the milk was freezing onto or thawing off from the cooler there was no difference in flavor.

The Effect of Different Methods of Sterilizing the Cooler on the Flavor of the Milk. Foreign flavors, especially metallic, oxidized and tallowy, are often found in milk due to faulty plant practices and equipment. Some of these have been attributed to the use of chlorine disinfectant in sterilizing equipment. It seemed desirable to know what effect chemical sterilization of the cooler had on the flavor of the milk.

Milk was obtained from the college herd, discarding the first milk to come in contact with any piece of equipment. Two, rust free, 40 quart cans were carefully washed and steamed for several minutes and this milk was placed in them, The milk was taken immediately to the creamery where it was pasteurized and divided into three equal portions. One portion of it was cooled over cooler "B" which had been sterilized 24 hours before with a chlorine sterilizer that contained 200 parts per million available chlorine. The cooler was then washed and sterilized with a similar solution and another portion of the milk cooled immediately. The cooler was then washed and sterilized with steam and another portion cooled.

Half pint samples were taken from each batch after cooling and stored in the cooler at 35° F. These samples were examined for flavor at the end of 0, 24, 48 and 72 hours by four judges. The results are shown in Table VII.

TABLE VII

The Effect of Different Methods Used in Sterilizing a Cooler on the Flavor of the Milk

Treatment of Cooler	Number of times cardboard flavor appeared*			
	Fresh	24 hrs.	48 hrs.	72 hrs.
Check (cooled in bottle)	0	0	0	0
Sterilized with chlorine rinse 24 hours before use	8	13	12	15
Sterilized with chlorine rinse just prior to use	3	9	10	16
Sterilized with steam	0	0	3	3

* Four trials and four judges.

A cardboard flavor usually first appeared in the samples cooled after chemical sterilization of the cooler at the end of the 24 hour period and grew stronger up to 72 hours. In the case of sterilization of the cooler just prior to use, the flavor tended to be medicinal.

A trial was made cooling the milk from 90° F. The flavor seemed to be less pronounced in this case so another trial was made in which the cooler was divided in such a way that half of a lot of milk could be cooled from 90° F. on one half of the cooler and the rest of the milk heated to 142° F. and cooled on the other half of the cooler.

The results indicated that the off flavor is less pronounced, especially at the 48 and 72 hour periods, in the case of the milk cooled from 90° F.

Two trials were made in which milk was cooled in an internal tubular preheater by circulating cold water through the jacket. In this manner the milk was not exposed to the atmosphere during cooling. The milk could only be cooled to about 60° F. in this manner so after the samples were taken, the bottles were placed in ice water to complete the cooling. The apparatus was sterilized four hours before and just prior to use as in the case of the surface cooler. All open parts of the line were washed out after sterilization. The results were practically the same as when cooler "B" was used.

A trial was made on cooler "B" in which 20 gallons of milk were run over the cooler, which had been sterilized 24 hours before with a chlorine rinse. Samples were taken from the trough at the end of each 5 gallons. The results showed that the effect of the sterilizer gradually diminished. It was much less but still noticeable after 20 gallons of milk had been cooled.

Oxidation reduction potentials were run on samples that had been run over the cooler after sterilization with a chlorine solution and on check samples using a saturated KCl calomel half cell and a Leeds and Northrup potentiometer. The electrode used was of platinum wire. The results are shown in Table VIII.

TABLE VIII

Oxidation Reduction Potentials of Milk Developing and Milk not Developing an oxidized Flavor

Average of two trials	Oxidation Reduction Potentials (millivolts)			
	Fresh	24 hrs.	48 hrs.	72 hrs.
Milk Developing an Off Flavor	-133	-143	- 140	-150
Milk not Developing an Off Flavor	-127	-135	- 141	-150

The potentials of the samples that developed the off flavor were from 0-10 millivolts more negative than those that did not develop the off flavor. The greater differences coming at the time the off flavor was developing.

A Study of Evaporation Losses During Cooling

It is a well known fact that there is always some shrinkage in processing milk. One point where loss may take place is during the cooling process. The passing of hot milk over the tubes of a surface cooler in a thin film affords an opportunity for loss due to evaporation.

An attempt was made to measure this loss in several different ways. The first method used was to weigh the milk before and after cooling. This was unsatisfactory as the loss due to other causes could not be definitely determined. Spillage and leakage were also practically inevitable. The error in weights was also large in comparison to the amount of evaporation.

A second method was to test for some constituent by a method sensitive enough to show small percentages of evaporation. One method of doing this was by the Mojonnier fat and solids test. Any loss due to evaporation would show up in increased percentage of fat and total solids in the milk. This was accomplished by testing the milk from the vat and from the cooler. The refractive index was also determined on these samples.

After several trials it was decided that the evaporation was too small to be determined by either of these methods.

It was thought, however, that an error in the interference refractometer might result from precipitation of the casein and fat in an attempt to get a clear solution for these determinations.

A solution of salt having the same surface tension as milk was made up. This was pasteurized and samples taken from the vat and from the cooler and their refractive index determined from this.

Six trials were made running the Mojonnier and interference refractometer tests. In each trial six replicate samples were taken from the vat and six from the cooler. The results are shown in Table IX.

The formula used in figuring the per cent change in water from the Mojonnier test was as follows:

$$\frac{\dfrac{100}{\text{Per cent Fat (or Solids)(Vat Sample)}} - \dfrac{100}{\text{Per cent of Fat (Cooled Sample)}}}{\dfrac{100}{\text{Per cent Fat(Vat Sample)}}} =$$

Per cent change in volume = Per cent change in water.

Explanations:-

1. $\dfrac{100}{\text{Per cent Fat(Vat Sample)}}$ = Amount of vat milk to yield one unit of fat.

2. $\dfrac{100}{\text{Per cent Fat(Cooled Sample)}}$ = Amount of cooled milk to yield 1 unit of fat.

The difference between 1 and 2 equals the change in volume which it is assumed is water.

This difference divided by the original milk equals the per cent change.

While it is obvious that the limits of error of this test are too large to determine the small amount of evaporation, there would seem to be certain conclusions that could be drawn from the data in Table IX.

The amount of evaporation over the cooler is very small. In fact, it is probable that there is just as apt to be condensation from the air as evaporation. The fact that in two trials the Mojonnier tests showed an increase in water and that the refractive index agreed in the only one of these trials that it was run on would seem to prove that there is condensation at times anyway. There is no question but that the milk is below the dew point some of the time. The dew point is the temperature at which the air would become saturated with a given amount of moisture. If it becomes cooled below this point some of the moisture will be precipitated. It is probable that evaporation takes place over the top of the cooler and condensation on the bottom.

One of the more important variables in this test would be relative humidity. During the first trial the humidity was nearly 100 per cent. During the final trial it reached 74 per cent. It will be noticed that there was condensation during both of these trials. The relative humidity varied

TABLE IX

Data Tending to Show the Amount of Evaporation Over the Surface Cooler

Sample Number	Per cent of Fat		Per cent Total Solids		Refractive Index	
	Vat	Cooler	Vat	Cooler	Cooler Per cent Gain	Vat Per cent Loss
Trial 1						
1	4.233	4.250	12.84	12.71	1.410	
2	4.208	4.232	13.01	12.84		0.620
3	4.250	4.230	13.00	12.77	0.097	
4	4.266	4.261	12.89	12.88	0.000	
5	4.307	4.302	12.92	12.82	0.370	
6	4.298	4.275	12.96	12.80	0.280	
Average	4.270	4.263	12.94	12.80	0.350	
Trial 2						
1	4.326	4.422	13.38	13.47	0.000	
2	4.371	4.380	13.57	13.47		0.117
3	4.353	4.368	13.30	13.21	0.000	
4	4.357	4.325	13.31	13.47	0.000	
5	4.294	4.308	13.50	13.48	-	-
6	4.300	4.351	13.31	13.44	0.000	
Average	4.338	4.336	13.41	13.47		0.234
Trial 3						
1	4.188	4.177	13.09	12.96	0.157	
2	4.073	4.208	12.94	13.12	0.410	
3	4.085	4.155	13.11	13.09		0.000
4	4.215	4.177	13.10	12.98	0.000	
5	4.137	4.202	13.05	12.91	0.881	
6	4.177	4.192	12.90	12.78		0.117
Average	4.130	4.186	13.02	12.98	0.1305	
Trial 4						
1	4.374	4.421	13.36	13.61		0.000
2	4.300	4.385	13.38	13.22	-	-
3	4.345	4.315	13.22	13.22	0.490	
4	4.299	4.354	13.12	13.22		0.122
5	4.346	4.334	13.00	13.40		0.427
6	4.331	4.378	13.47	13.25	0.108	
Average	4.345	4.377	13.34	13.34		0.1704

TABLE 12 - Continued

Sample Number	Per cent of Fat		Per cent Total Solids		[illegible]	
					Cooler Per cent Gain	Vat Per cent Loss
	Vat	Cooler	Vat	Cooler		
Trial 5						
1	4.287	4.303	13.38	13.31		0.351
2	4.309	4.298	13.14	13.12		0.032
3	4.302	4.307	13.24	13.35	0.148	
4	4.284	4.297	13.22	13.28	0.225	
5	4.311	4.293	13.16	13.22	0.105	
6	4.311	4.327	13.32	13.34	0.170	
Average	4.294	4.311	13.23	13.27	0.076	
Trial 6						
1	4.207	4.230	13.14	12.93		
2	4.271	4.309	13.30	12.90		
3	4.204	4.227	13.17	12.81		
4	4.278	4.241	13.24	12.99		
5	4.230	4.252	13.45	13.05		
6	4.215	4.239	13.45	13.05		
Average	4.230	4.251	13.33	12.96		
Trial	Average of Six Trials					
1	4.270	4.283	13.04	13.30	0.205	
2	4.358	4.335	13.41	13.47		0.234
3	4.130	4.156	12.93	12.96	0.1265	
4	4.346	4.377	13.24	13.24		0.1704
5	4.294	4.311	13.23	13.27	0.076	
6	4.230	4.251	13.33	12.96		
Average	4.270	4.281	13.21	13.15		
Per cent Gain or Loss in Water						
	.124		1.250		.205	
	-.500		- .447		-0.0234	
	-1.330		.560		.1265	
	-.709		.000		-.1704	
	-.162		-.302		.076	
	.608		3.409		——	
Average	-.3475		.064		.037	

from 60 to 74 per cent in 15 minutes during one trial. This factor alone could cause large variation in evaporation.

The results of the interference refractometer tests on a salt solution, samples being taken from the vat and other samples after the solution had been cooled over cooler "A" - are shown in Table I. All samples were tested in duplicate being read against sample number one. There was never more than one division difference in duplicate tests. One division on the interferometer being equal to .025 per cent change in water. Consequently any differences must be in the samples rather than due to error in the test.

Sample one is taken from the vat before heating, sample two from the vat as soon as the solution reached 142° F., sample three from the vat at the end of 30 minutes holding period. The "A" samples are taken from the vat and the "B" samples from the cooler.

In trial one the valve on the cooling brine was changed from time to time in an effort to get maximum cooling without any solution freezing onto the tubes. This probably accounts for some of the variation. In the other trials the whole lot was allowed to run over the cooler without any changes after sampling was started. It will be noticed that the results are more uniform in these trials, especially trial two.

TABLE X

Per cent of Evaporation of a Salt
Solution Over a Surface Cooler

Sample Number	Per cent change in water/Sample 1 Trial 1	Trial 2	Trial 3	Trial 4	Per cent change in water B/A Trial 1	Trial 2	Trial 3	Trial 4
2	.075	- .076		- .033				
3	-.600		.230	- .184				
4A	-.425	- .235	.358	- .248				
4B	-.088	- .500	[illegible]	[illegible]	- .490	- .074	-1.060	.061
5A	-.175	- .324	- .659	- .230				
5B	[illegible]	- .274	[illegible]	[illegible]	- .000	.000	-2.004	- .170
6A	.100	- .339	-3.402	- .246				
6B	[illegible]	- .309	-2.084	[illegible]	.050	.004	- .309	- .350
7A	.250	- .397	-3.709	- .304				
7B	-.400	[illegible]	-3.721	- .281	- .660	.008	- .802	.230
8A	2.975	- .384	-3.607	- .281				
8B	4.500	[illegible]	[illegible]	- .280	1.035	.000	- .481	- .284
9A	5.480	- .459	-4.221	- .292				
9B	4.430	- .435	-4.477	- .335	.950	.025	- .256	- .459
Average B/A					.233	.013	- .971	- .190

Average of 4 trials B/A = - .225

In trials three and four conditions were as favorable for evaporation as one would expect to find. The air temperature was 85° F. with a relative humidity of 30 per cent. The cooling brine was fairly warm so the solution did not get cooled until it reached the bottom of the cooler. It could not have been below the dew point very long. In trial four the solution was only cooled to 48° F. In addition to this, a large fan was placed at the end of the cooler causing a rapid flow of air across the cooler during these trials.

It will be noticed that the first two samples - 4B/4A and 5B/5A in each trial, show much greater evaporation than subsequent ones. This may be due to the fact that the samples were taken before the system had come to equilibrium. It is possible that more evaporation takes place for the first few minutes. This might be because the surroundings have not been cooled down and the air is less saturated. If these samples were disregarded there would be a much smaller percentage of evaporation.

This work bears out the results shown in Table II where milk was used. The amount of evaporation from the cooler is very much smaller and there is often a gain in water. It would seem safe to assume that the average evaporation from a surface cooler is 0.2 per cent.

SUMMARY

Milk was allowed to freeze on the tubes of a surface cooler and examined for flavor and creaming ability. The flavor of the frozen portion was impaired and the cream layer reduced on the average by 38 per cent.

Studies were made on the effect of various brine temperatures on creaming ability. There seemed to be little if any difference comparing brines of 0, 1, 12 and 10° F. with brines of 18, 20, 30 and 38° F.

Milk was run over the cooler at different rates to determine the effect on creaming ability. The rate of flow seemed to have little effect.

Milk was run over coolers of different heights in an effort to determine the effect of distance of fall on the creaming ability of milk. This factor also seemed to have little effect.

Milk was cooled to 35, 40, 45 and 50° F. and stored in, 1. water at 35° F., 2. water at 45° F., and 3. air at 45° F. The storage temperature seemed to have more effect on volume of cream rising than the temperature to which the milk was cooled, 35° F. giving the maximum cream layer.

Milk was allowed to freeze and then cream. The cream line was uneven and had a coagulated appearance and the cream refused to remix readily with the serum.

The cooler was sterilized with a chlorine solution containing 200 parts per million available chlorine. Twenty-four hours later milk was cooled over this cooler. The cooler was then washed and sterilized and more milk cooled immediately. The cooler was again washed but sterilized with steam and more milk cooled. The samples that were cooled after the chlorine sterilization had a tallowy, oxidized taste which increased in intensity with age.

A study of evaporation losses made by running the Mojonnier fat and solids tests on the milk before and after cooling and the interference refractometer tests on milk and salt solutions revealed that the evaporation was very small. The Mojonnier tests gave a loss of .3475 per cent and a gain of .004 per cent. The refractometer gave a gain of .007 per cent.

CONCLUSIONS

From this work the following conclusions seem justified:

1. Freezing of milk causes a tallowy, oxidized, metallic flavor and reduces the cream layer an average of 20.00 per cent.

2. The effect of freezing is unnoticed during normal continuous operation of the cooler.

3. Other factors in cooling, e.g., rate of flow of milk over the cooler, distance of fall of milk over the cooler,

thickness of film of milk on the cooler, and temperature of cooling media, have very little if any effect on depth of cream layer or flavor.

4. Freezing of milk causes a coagulated appearance of the cream layer and an uneven cream line. The cream will not mix back into the serum readily. This is due to destabilization of the fat emulsion.

5. The nearer 35° F. the milk is stored, the deeper the cream layer.

6. Evaporation from the cooler is very slight. In fact there may be condensation of moisture from the air. The average evaporation is probably 0±.2 per cent.

7. Sterilizing a cooler with a chlorine rinse causes a cardboard flavor in milk cooled over the cooler. This is due to oxidation of some substance in the milk, probably fat. The flavor is more marked if the milk is cooled from 142° F. than from 90° F. As more milk is passed over the cooler, the off flavor becomes less intense. A suggested remedy is to rinse the cooler with a large volume of hot water before using.

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